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(54) **Sealless integral-motor pump with regenerative impeller disc**

(57) A fluid pump comprises a cylindrical shaft (15) mounted in a housing (20) having a fluid passage (27) radially outboard of the shaft and extending circumferentially between at least one fluid inlet port (25) and at least one fluid discharge port (30). The ports are separated by an interruption (29) of the fluid passage located upstream of the inlet and downstream of the discharge. At least one rotatable regenerative rotor disc (10) is mounted on the shaft, the disc having a plurality of radially orientated impeller vanes (12) situated about the periphery thereof within the fluid passage (27) and also having a plurality of permanent magnets (110) embedded therein in a circular locus about the shaft, the magnets being sealed against pumped fluid. At least one set of motor windings (120) is encased in at least one wall of the housing axially adjacent the permanent magnets in the regenerative rotor disc and also sealed against pumped fluid. Means (250) is provided for controlling a flow of electricity through the motor windings to drive the rotor disc. The shaft may be supported in the housing in lubricated bearings or in magnetic bearings, or alternatively, the rotor disc may be rotatably supported on the shaft on lubricated bearings or on magnetic bearings.

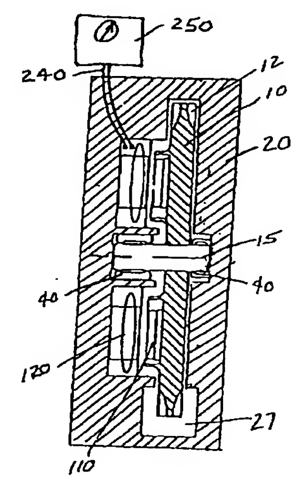

FIG 1

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Description

[0001] This invention relates generally to fluid pumps and more particularly to high-pressure-rise, low-flow-rate charging pumps for providing make-up fluids to closed high-pressure systems.

[0002] For applications such as charging pumps for supplying make-up fluid to closed high-pressure systems, it is necessary to employ pumps capable of supplying relatively low-flow-rate fluid at high pressure. It is desirable for such pumps to be highly leak resistant because of the types of fluids and the pressures involved. The most favoured method of providing such leak resistance is by employment of sealless pumps. Sealless pumps often incorporate motors located inside the pump case, so there are no shaft pass-throughs to seal against leakage of the pumped fluid.

[0003] Current high-pressure-rise, low-flow-rate pumps are typically positive-displacement reciprocating pumps which are highly efficient, but, because of the necessary rotary-to-reciprocating motion converters, are large and difficult to configure as sealless pumps. Thus, when environmental considerations are important, the sealless feature becomes more important and positive-displacement reciprocating pumps become less practical due to the difficulty of adapting a reciprocating drive to a sealless pumpage-tolerant coupling mechanism. This is a serious drawback since many sealless applications rely on product lubricated bearings to reduce friction and wear in the pump equipment.

[0004] Although rotodynamic pumps are less efficient than are positive displacement pumps, they have the advantage of being much more amenable to sealless designs than are reciprocating positive displacement designs. Rotodynamic pumps are also more easily configured as sealless multi-stage machines, which permits their use in very high pressure applications. Thus, reciprocating positive displacement pumps, although more efficient than single-stage rotodynamic pumps, lose some of that efficiency advantage when multi-stage sealless features are employed.

[0005] According to one aspect of the present invention, there is provided a fluid pump comprising a cylindrical shaft; a housing supporting ends of said shaft and having at least one fluid passage radially outboard of said shaft and extending circumferentially between at least one fluid inlet port and at least one fluid discharge port, said ports being separated by an interruption of said fluid passage located upstream of said at least one inlet and downstream of said at least one discharge; at least one rotatable regenerative rotor disc mounted on said shaft, said disc having a plurality of radially orientated impeller vanes situated about the periphery thereof, within said fluid passage, and also having a plurality of permanent magnets embedded therein in a circular locus about said shaft, said magnets being sealed against pumped fluid; at least one set of motor windings encased in at least one wall of said housing axially adjacent the permanent magnets in said at least one regenerative rotor disc and also sealed against pumped fluid; and means for controlling a flow of electricity through said motor windings to rotatably drive said rotor disc.

[0006] According to a second aspect of the present invention, there is provided A fluid pump comprising a housing having two endwalls, each said endwall having a circular recess bounded by a circumferentially extending fluid passage groove such that, when butted together, said recesses from a pumping chamber and said grooves form a fluid passage extending between at least one inlet port and one discharge port, said fluid passage having an interruption at an upstream edge of said inlet port and a downstream edge of said discharge port; a circular regenerative rotor disc within the pumping chamber between said housing endwalls, said rotor disc having a plurality of substantially radially extending impeller vanes arrayed about its periphery, and a plurality of permanent magnets embedded in a circular locus about the centre of said rotor disc, said magnets being sealed against contact with pumped fluid; motor windings encased in said housing endwalls and sealed against contact with said pumped fluid for acting with said permanent magnets to rotatably drive said rotor disc; means for providing electric power to said motor windings; and means for rotatably supporting said rotor disc in said housing.

[0007] For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:-

Fig. 1a is a fragmentary schematic radial sectional view of a single stage of a single pass regenerative pump;

Fig. 1b is a schematic axial sectional view, along line b-b of Fig. 1a, of a single stage sealless axially magnetically unbalanced embodiment of a single-pass regenerative pump;

Fig. 1c is a fragmentary schematic axial sectional view, along line c-c of Fig. 1a, of a single stage of an axially magnetically balanced embodiment of a sealless single-pass regenerative pump;

Fig. 1d is a schematic axial sectional view of a sealless two-stage, single-pass regenerative pump;

Fig. 2a is a fragmentary schematic radial sectional view of a sealless two-pass regenerative pump;

Fig. 2b is a schematic axial section, along line b-b of Fig. 2a, of a sealless two-stage, two-pass regenerative pump;

Fig. 3a is a fragmentary axial sectional view of a rotor disc mounted on a shaft supported in product-

lubricated bearings of a sealless pump;

Fig. 3b is a view, as in Fig. 3a, of a shaft supported in magnetic bearings in a sealless pump;

Fig. 4a is a fragmentary axial sectional view of a rotor disc supported on product-lubricated bearings on a stationary shaft of a sealless pump;

Fig. 4b is a view, as in Fig. 4a, of a rotor supported on magnetic bearings;

Fig. 5 is a fragmentary schematic view of a single stage of another embodiment, as in Fig. 1c, of the axially magnetically balanced sealless integral motor regenerative rotor disc pump;

Figs. 6a and 6b are fragmentary sectional illustrations of the shaft and the regenerative rotor disc, respectively, rotatably supported on conical magnetic bearings in the housing; and

Fig. 6c is fragmentary sectional illustration of a recess in the housing for supporting either the shaft or the rotor disc on magnetic bearings.

[0008] Fig. 1a shows a partially sectional view of a single stage of a single pass regenerative pump. The pump has a housing 20 with a single inlet port 25 and a single discharge port 30 which are connected by a fluid passage 27 extending circumferentially between the inlet and outlet ports. An interruption 29 of the fluid passage separates the upstream edge of the inlet port 25 and the downstream edge of the discharge port 30. Thus, fluid entering the inlet port 25 is caught by impeller vanes 12 on the rotor 10, which is rotating on a shaft 15 supported in the axial endwalls of the housing 20, and driven along the fluid passage 27 to the discharge port 30. The interruption 29 of the passage guides the fluid into the discharge port. The ports 25, 30 are shown with corners only as a simplified representation, but are normally provided with radii appropriate to the fluid being pumped in accordance with well known porting practice. The vanes 12 are shown as straight and radial for the sake of illustrative simplicity. In fact, they may be straight with an inclination angle to the axis or the tangent of the rotor disc 10, and/or they may be curved in the axial and/or radial direction. The specific application determines the vane configuration. Axially opposite vanes of the disc may be offset from each other or may be axially aligned. The single-pass rotors shown are each radially hydrodynamically unbalanced due to the pressure rise between the inlet port 25 and the discharge port 30 in the fluid passage 27 which results in a resultant radial hydrodynamic force approximately opposite to the discharge port 30. In multistage pumps, these hydrodynamic forces may be offset by placement of the inlet and discharge ports diametrically opposite in two stage pumps or by radially distributing them about the housings to balance the hydrodynamic forces in pumps exceeding two stages.

[0009] Figs. 1b and 1c, are views along line b/c-b/c of Fig. 1a and show the integral motor features of the regenerative rotor pump. A brushless DC motor is provided by means of the embedded circular array of permanent magnets 110 in the rotor disc 10 in conjunction with a stator comprising the motor windings 120 encased in the housing 20. The resulting magnetic coupling between the permanent magnets 110 and the motor windings 120 provides the brushless motor drive desired for the sealless pump. Fig. 1b illustrates an axially magnetically unbalanced rotor disc 10 with embedded permanent magnets 110 on one face adjacent to motor windings 120 embedded in the housing 20 and are powered by electric current introduced through electric leads 240 which are fed through the stationary housing 20 to a motor controller 250. The magnets 110 and motor windings 120 are sealed against contact with the pumped fluid. The shaft 15 on which the disc 10 is mounted is supported in the housing 20 in bearings 40 which may be of journal or antifriction types. The fluid passage 27 is shown with a rectangular cross-section, again only as a simplified representation, but will preferably be provided with a cross-sectional geometry compatible with the regenerative flow profile of the pumped fluid caused by the pumping action of the impeller vanes 12. The fragmentary view in Fig. 1c is of a single stage of an axially magnetically balanced integral motor regenerative rotor disc 10'. In this design, permanent magnets 110 are embedded in both faces of the rotor disc 10 and are rotatably driven by electromagnetic forces from the motor windings 120 in the walls of the housing 20 adjacent to the web of the rotor disc. An alternative embodiment of this axially magnetically balanced pump is shown in Fig. 5, in which a single set of permanent magnets 210 are embedded in the rotor 10" to react to motor windings 120 in both axially adjacent housing walls. This has the advantage of reducing the mass and volume and smoothing the radial profile of the web of the rotor disc 10" relative to that of disc 10' in Fig. 1c, thereby simplifying design and fabrication of the rotor disc 10" and the axially adjacent walls of the housing 20.

[0010] Figs. 1d and 2b show two stage sealless regenerative pumps, one-pass and two-pass versions, respectively. It should be noted that the housing 20 in all Figures is shown schematically without seams. In reality, the housing may be comprised of a plurality of torroidal discs bounding a plurality of rotor discs with solid endwalls enclosing the discs. In both cases, the pumps are axially magnetically balanced due to the oppositively situated motor windings 120 in the endwalls of the housing 20 acting on the permanent magnets 110 embedded in the faces of the discs 10 adjacent to the endwalls in which the windings are encased. Of course, this design can accommodate many more than two

stages, in which case axial balancing would only require equal numbers of opposed motor winding sets. In both Figs. 1d and 2b, the housings 20 support the shafts 15 in bearings 40. Regenerative rotor discs 10 with substantially radially orientated impeller vanes 12 are mounted on shafts 15 and rotate within fluid passages 27 (not visible in Fig. 2b) between inlet ports 25 and discharge ports 30, separated by fluid passage interruptions 29. Permanent magnets 110 are embedded in the rotor discs 10 and are electromagnetically driven by the motor windings 120 in the endwalls of the housing 20.

[0011] Although the pumps shown in the Figs. 1d and 2b are axially balanced, thrust bearing assemblies 60 are provided between the stages to prevent the rotors rubbing the housing walls in case of mechanical or hydraulic axial shocks. In some service, thrust bearings may not be needed; therefore, when included, they do not contact the rotors during normal operation except when an axial upset is introduced to the system. The thrust bearing assemblies 60 and the radial bearings 40 may be product (or pumpage) lubricated journals or anti-friction bearings, or they may be magnetic bearings. The particular type is determined by service or performance factors.

[0012] The bearings in Figs. 3a, 3b, 4a and 4b are illustrated as radial bearings. These may be journals or anti-friction radial mechanical bearings 140 (Figs. 3a and 4a) which may be product (or pumpage) lubricated and cooled. Alternatively, they may be magnetic bearings comprised of permanent magnets 210, 230 embedded in the rotating member 10', 10", 15, 115 and electromagnets (or, optionally, permanent magnets) opposedly embedded in the stationary member 15", 20 to provide the required magnetic support. In the case where electromagnets are provided in the stationary member, electric leads 240 are fed out to an outside power source. These radial bearing systems provide radial support to the rotating member(s) within or in the stationery member(s).

[0013] The single-stage rotor 10" shown in Fig. 5 is axially magnetically balanced by magnetic forces between the motor windings 120 in the housing 20 and the permanent magnets 210 in the rotor. Only a single stage is illustrated, but any number of magnetically balanced stages may be mounted on the shaft 15 in added sections of the housing 20. The rotor 10" has the same impeller blades 12, and the housing has the same fluid passage as discussed above, but here each stage is axially magnetically balanced, independently of any other stages.

[0014] Clearly, conical bearings, of any type including product lubricated journals, anti-friction bearings, or magnetic bearings, which provide both radial and axial support may also be employed. Figs. 6a and 6b show one type of conical magnetic bearings for use with a rotor made from non-magnetisable material such as aluminium, bronze, polymers, etc. In Fig. 6a, the rotatable shaft 15' is supported on magnetic bearings comprising permanent magnets 315 in the shaft and electromagnets 320 in the housing wall 20'. The force field created between the magnets 315, 320 levitate the shaft within the conical cavity of the housing wall 20' and provide a friction-free axial and radial bearing support for the shaft 15'. When the magnetic forces are repulsive instead of attractive, permanent magnets could be used in both the shaft 15' and the wall 20'. Otherwise the electromagnets are needed to fine tune the position of the shaft, because they allow adjustment of the levitating forces. Fig. 6b shows a rotor supported on conical bearings of the housing 20" with no shaft. In this case, the rotating member (rotor 10*), being of non-magnetic material as in Fig. 6a, has permanent magnets 310 arrayed about opposed conic recesses radially centred on the rotor disc. For purposes of magnetic bearing suspension, it is only necessary that the rotating member be made of a magnetisable material. In such cases, the electromagnets and, if used, permanent magnets act directly upon the magnetisable rotating member to create the magnetic suspension. When made from a non-magnetisable material, the rotating member may alternatively be provided with a magnetisable susceptor at the appropriate location. Whether to locate the projections on the housing or on the disc is determined by manufacturing considerations, since the magnetic bearings are equally effective in both cases. In the example illustrated in Fig. 6b, electromagnets 320 or permanent magnets 310 are arrayed about conic axial projections of the housing 20". The force field created by these magnets provides magnetic combined radial and axial suspension to the rotor disc 10* without use of a shaft. The projections and recesses above have been described as conical, but may be of any form, such as hemispheric, cylindrical or combinations of forms.

[0015] In cases where magnetic bearings are used, it is preferred to provide small stand-off journals or auxiliary bearings 26, as in Fig. 6c, to approximately centre the rotor 10* and/or shaft 15' in the housing 20", 20'. This protects the magnets in the absence of electric power, including the permanent magnets which may also be those used for power transmission. In this case, the permanent magnets 310, 315 are embedded in the rotatable rotor disc 10* or shaft 15', while the electromagnets 320 are preferably provided on the conic projection of the housing 20" or the shaft 15'. The stand-off journals 26 may be of any suitable bearing material for service during start-up or transient operating conditions and are usually not in contact with the rotating member during steady-state operation of the fluid pump. When the rotor disc is made from, or has a susceptor feature made from a magnetisable material, permanent magnets in the disc may not be required for the magnetic suspension. However, they are still needed for the brushless DC integral-motor rotor feature previously described. Finally, a combined rotor drive and magnetic bearing suspension may be achieved by locating at least some of the permanent magnets in a radial posi-

tion in the rotor such that they can respond to both the electromagnetic fields of the motor windings and the magnetic force field of the suspension bearing electromagnets. In all cases, permanent magnets, if needed, are embedded in the rotary member; and the motor windings and the electromagnets are embedded in the stationary member, so that no rotating electrical contact is needed.

[0016] The present constructions provide the advantages of an integral-motor pump of a rotodynamic type which is readily amenable to sealless design, multistaging and operation with less than all stages running. By suitably manifolding between discharge ports of preceding phases or stages and inlet ports of succeeding phases or stages, operating total pressure-rise can be accurately varied as required. For example, operation of multiple stages in series would provide a substantially additive final discharge pressure; while operation of the same pump stages in parallel would provide substantially additive final discharge volume. When the rotors are individually rotatably supported on a stationary shaft or when a shaftless rotor design is incorporated, as described above, the pump can be operated with one, some, or all stages of a multistage configuration running. This, along with the manifolding above, permits previously unattainable versatility of operation.

[0017] The regenerative impeller-disc pump described herein has the advantage of being readily multistaged due to the fact that the suction and discharge ports are at the periphery of the pumping chamber. Thus, fluid passing from one stage or one phase to the next can do so without power-consuming provisions for directing the fluid radially inward to a central suction port as would be required with a standard centrifugal pump. This feature results in increased pumping efficiency.

Claims

1. A fluid pump comprising a cylindrical shaft (15); a housing (20) supporting ends of said shaft and having at least one fluid passage (27) radially outboard of said shaft and extending circumferentially between at least one fluid inlet port (25) and at least one fluid discharge port (30), said ports being separated by an interruption (29) of said fluid passage located upstream of said at least one inlet (25) and downstream of said at least one discharge (30); at least one rotatable regenerative rotor disc (10) mounted on said shaft, said disc having a plurality of radially orientated impeller vanes (12) situated about the periphery thereof, within said fluid passage (27), and also having a plurality of permanent magnets (110) embedded therein in a circular locus about said shaft (15), said magnets being sealed against pumped fluid; at least one set of motor windings (120) encased in at least one wall of said housing axially adjacent the permanent magnets in said at least one regenerative rotor disc (10) and also sealed against pumped fluid; and means (250) for controlling a flow of electricity through said motor windings to rotatably drive said rotor disc.

2. A pump according to claim 1, wherein said housing (20) has a plurality of diametrically opposed fluid inlet ports (25) and a plurality of diametrically opposed fluid discharge ports (30) in fluid communication with the fluid passage (27) about the vanes (12) of said at least one rotor disc (10) such that the rotor is radially hydrodynamically balanced, each inlet and outlet port being separated by a said interruption (29).

3. A pump according to claim 1 or 2, wherein said housing (20) contains a single rotatable regenerative rotor disc (10) mounted on said shaft (15) between two axial endwalls of said housing, each said endwall encasing a set of motor windings (120) such that the rotor is magnetically axially balanced.

4. A pump according to claim 1, wherein said housing (10) has two radially extending endwalls and at least one radially extending inner wall axially adjacent to and interposed between a plurality of regenerative rotor discs (10), each said radially extending wall having at least one fluid passage (27) extending between at least one fluid inlet port (25) and one fluid discharge port (30).

5. A pump according to claim 4, further comprising a fluid conduit extending from the fluid discharge port (30) of a first fluid passage to the fluid inlet port (25) of a second fluid passage, and so on, such that each succeeding regenerative rotor disc (10) of said plurality of rotor discs has a higher inlet and discharge pressure than that of the preceding disc.

6. A pump according to any one of the preceding claims, wherein said shaft (15) is rotatably supported in said housing (20) in lubricated bearings (40).

7. A pump according to any one of claims 1 to 5, wherein said shaft (15) is rotatably supported in said housing (20) in magnetic bearings (210, 230).

8. A pump according to any one of claims 1 to 5, wherein the ends of said shaft (15) are fixedly supported within said housing (20) and said at least one rotor (10) is rotatably supported on said shaft on lubricated bearings (140).

9. A pump according to any one of claims 1 to 5, wherein the ends of said shaft (15) are fixedly supported within said housing (20) and said at least one rotor (10) is rotatably supported on said shaft

on magnetic bearings (230).

10. A pump according to any one of the preceding claims, wherein said fluid passage (27) radially outboard of said shaft (15) is provided by a circumferential groove in said housing (20), said groove being interrupted by said interruption (29).

11. A fluid pump comprising a housing having two endwalls, each said endwall having a circular recess bounded by a circumferentially extending fluid passage groove such that, when butted together, said recesses from a pumping chamber and said grooves form a fluid passage extending between at least one inlet port and one discharge port, said fluid passage having an interruption at an upstream edge of said inlet port and a downstream edge of said discharge port; a circular regenerative rotor disc within the pumping chamber between said housing endwalls, said rotor disc having a plurality of substantially radially extending impeller vanes arrayed about its periphery, and a plurality of permanent magnets embedded in a circular locus about the centre of said rotor disc, said magnets being sealed against contact with pumped fluid; motor windings encased in said housing endwalls and sealed against contact with said pumped fluid for acting with said permanent magnets to rotatably drive said rotor disc; means for providing electric power to said motor windings; and means for rotatably supporting said rotor disc in said housing.

12. A pump according to claim 11, wherein the means for rotatably supporting said rotor disc in said housing comprises conical bearings projecting axially from said housing endwalls into conical recesses in said rotor disc.

13. A pump according to claim 11, wherein the means for rotatably supporting said rotor disc in said housing comprises conical bearings on the ends of a shaft on which said rotor disc is mounted, said conical bearings engaging in conical recesses in said housing endwalls.

14. A pump according to claim 11, wherein the means for rotatably supporting said rotor disc in said housing comprises projections extending axially from one of said rotor disc or said housing walls, said projections featuring bearings for engaging in congruent recesses in the other of said housing walls or said rotor disc.

15. A pump according to any one of claims 11 to 14, further comprising at least one housing inner wall having circular recess and a circumferentially extending groove on each axial face, such that, when interposed between said endwalls, said at least one inner wall forms at least two pumping chambers surrounded by at least two fluid passages extending between at least two inlet ports and two outlet ports; and at least two circular regenerative rotor discs rotatably supported within said at least two pumping chambers.

16. A pump according to claim 15, further comprising at least one fluid conduit, external to the pumping chambers, extending between the discharge port of one pumping chamber and the inlet port of a second pumping chamber.

17. A pump according to claim 15, further comprising a fluid conduit for receiving pumped fluid from all discharge ports simultaneously for combining volumetric flow from all stages of said pump.

18. A pump according to any one of claims 11 to 17, further comprising at least one housing inner wall having a circular recess and a circumferentially extending groove on each axial face, such that, when interposed between said endwalls, said at least one inner wall forms at least two pumping chambers surrounded by at least two fluid passages extending between at least two inlet ports and two discharge ports; at least two circular regenerative rotor discs rotatably supported within said at least two pumping chambers; means for separately receiving pumped fluid from each of said at least two discharge ports for either combining flows or for maintaining separation of said flows; and means for individually rotatably driving said regenerative rotor discs such that only those discs needed for the pumping requirements at any given time are driven.

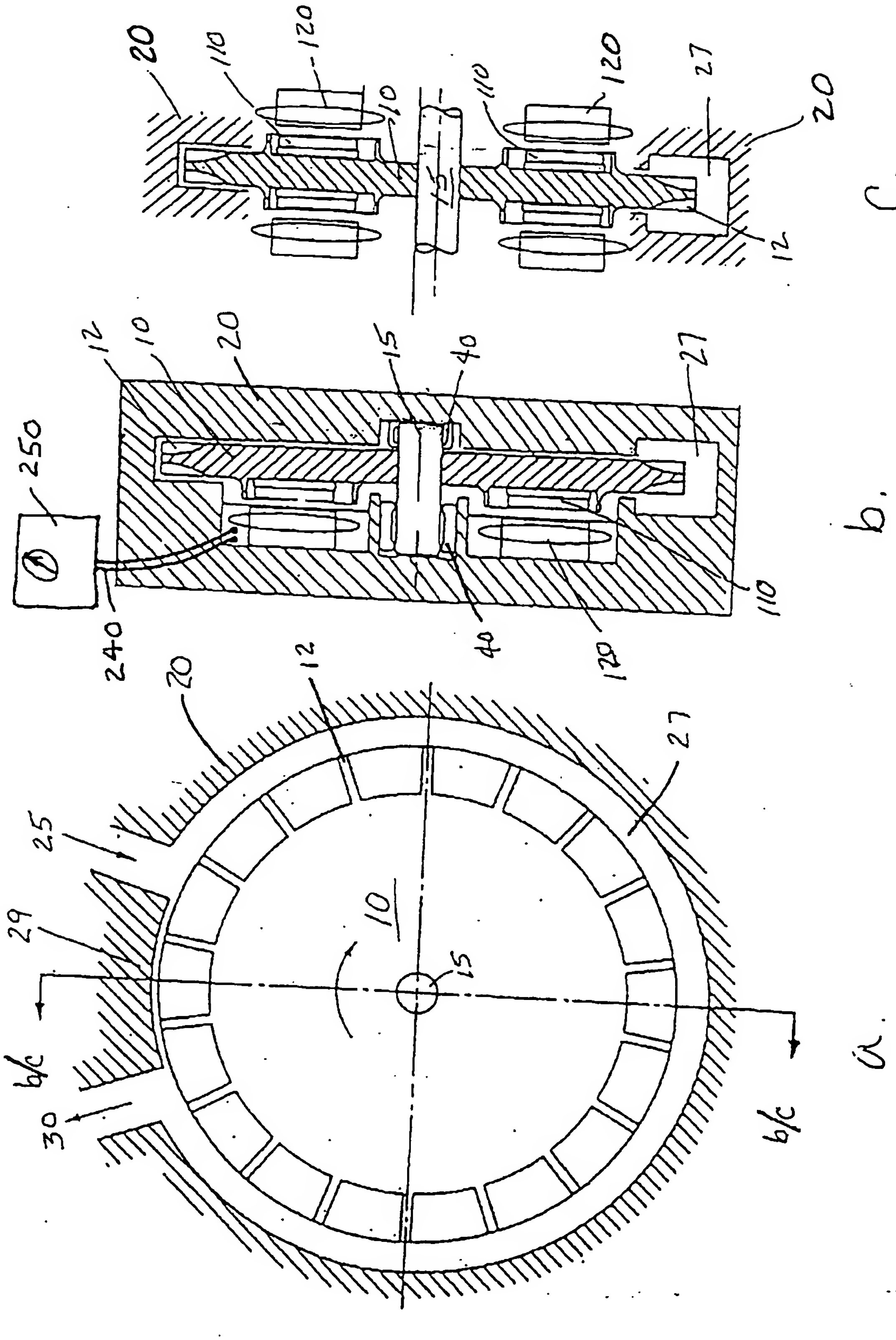
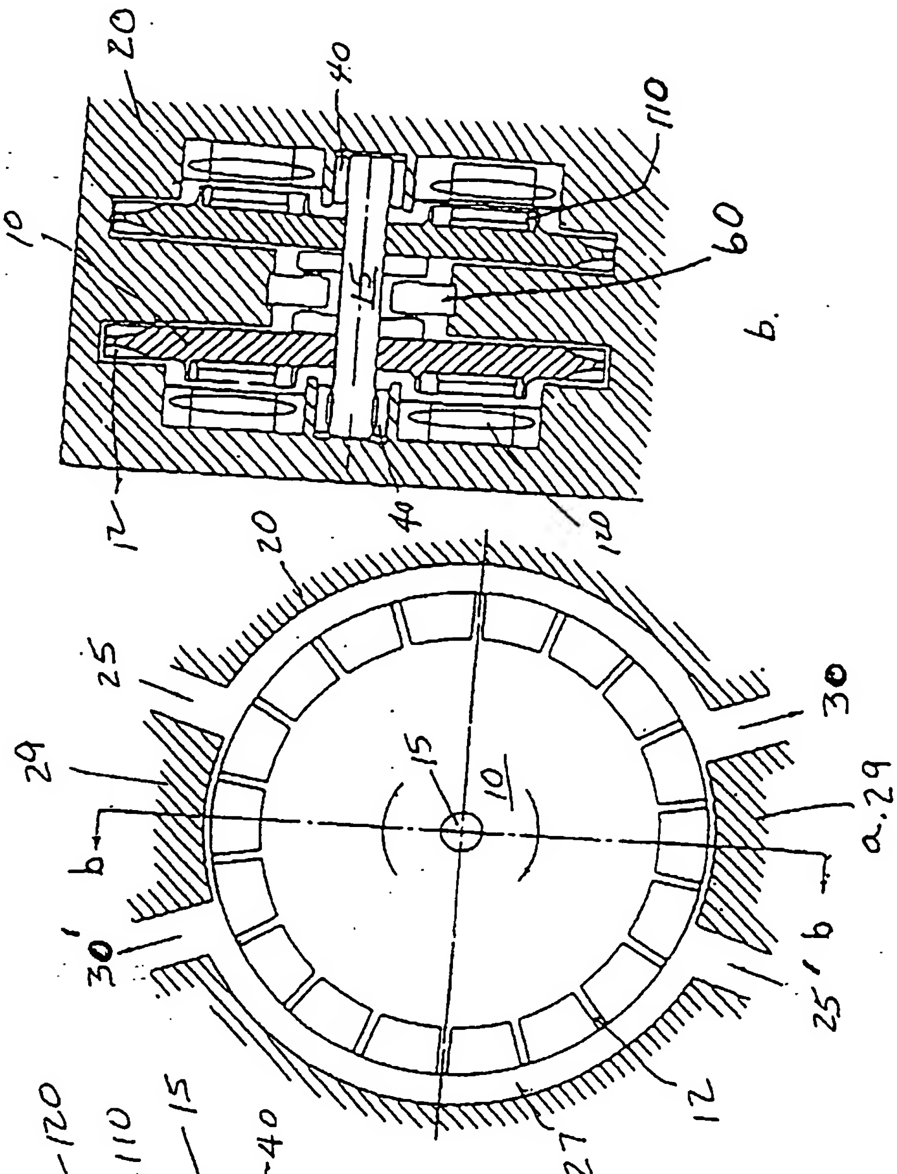


FIG 1


20
40
10
110
60
15
b.
12
40
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20
25
29
15
10
30
b
a.29
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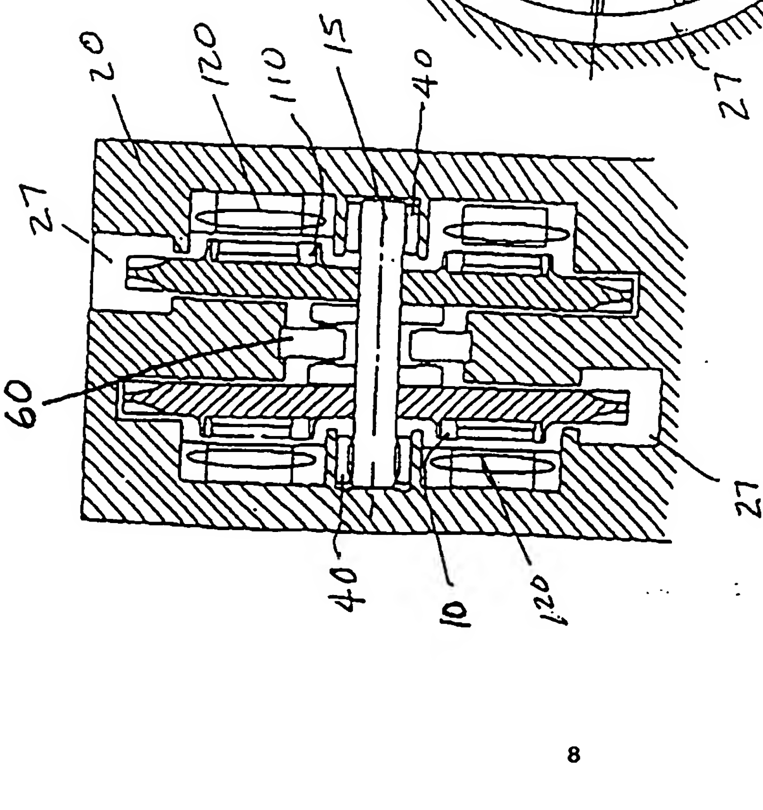
b
25'
12
27

FIG. 2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27
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27
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10
120

FIG. 1d.

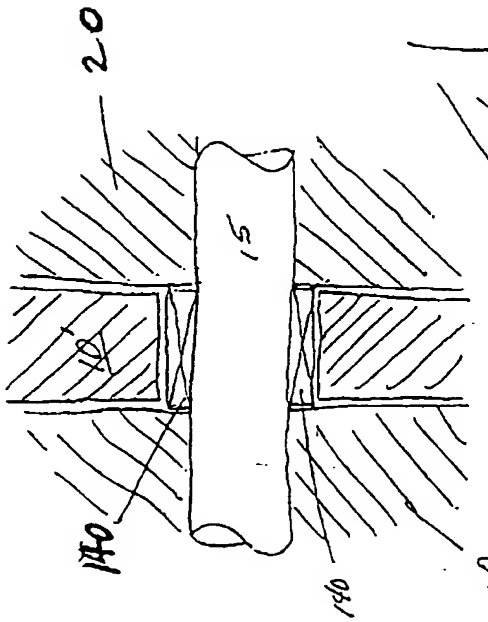


FIG. 4a

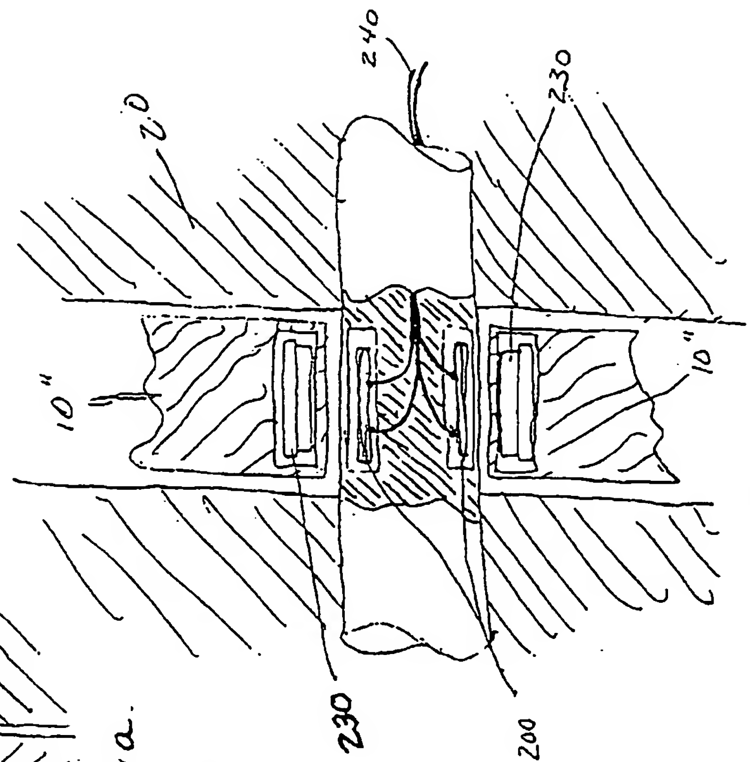


FIG. 4b

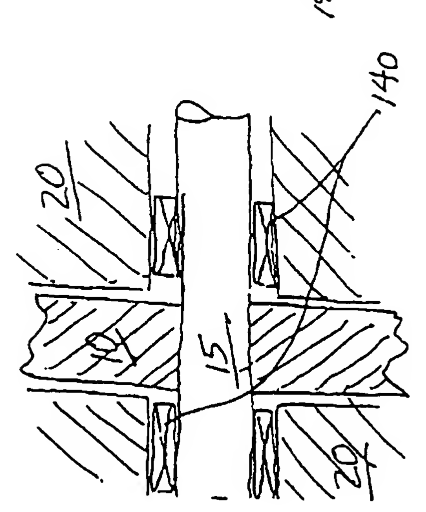


FIG. 3a.

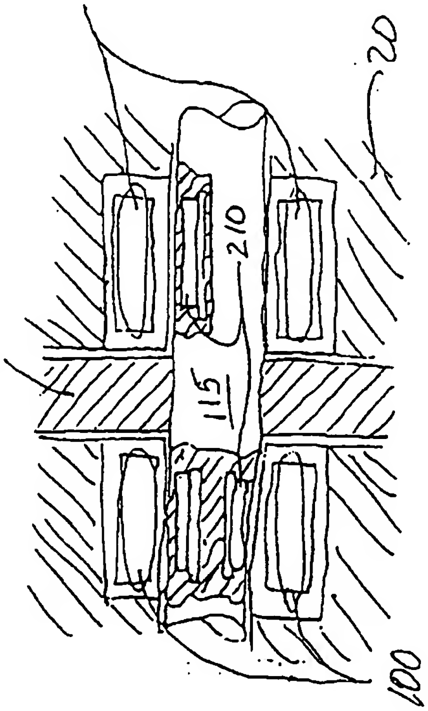
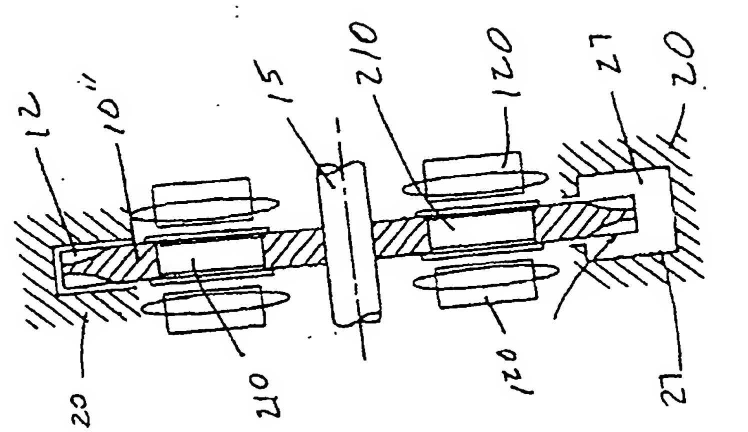


FIG. 3b.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10''
15
210
120
27
20
20
210
120
27

FIG. 5

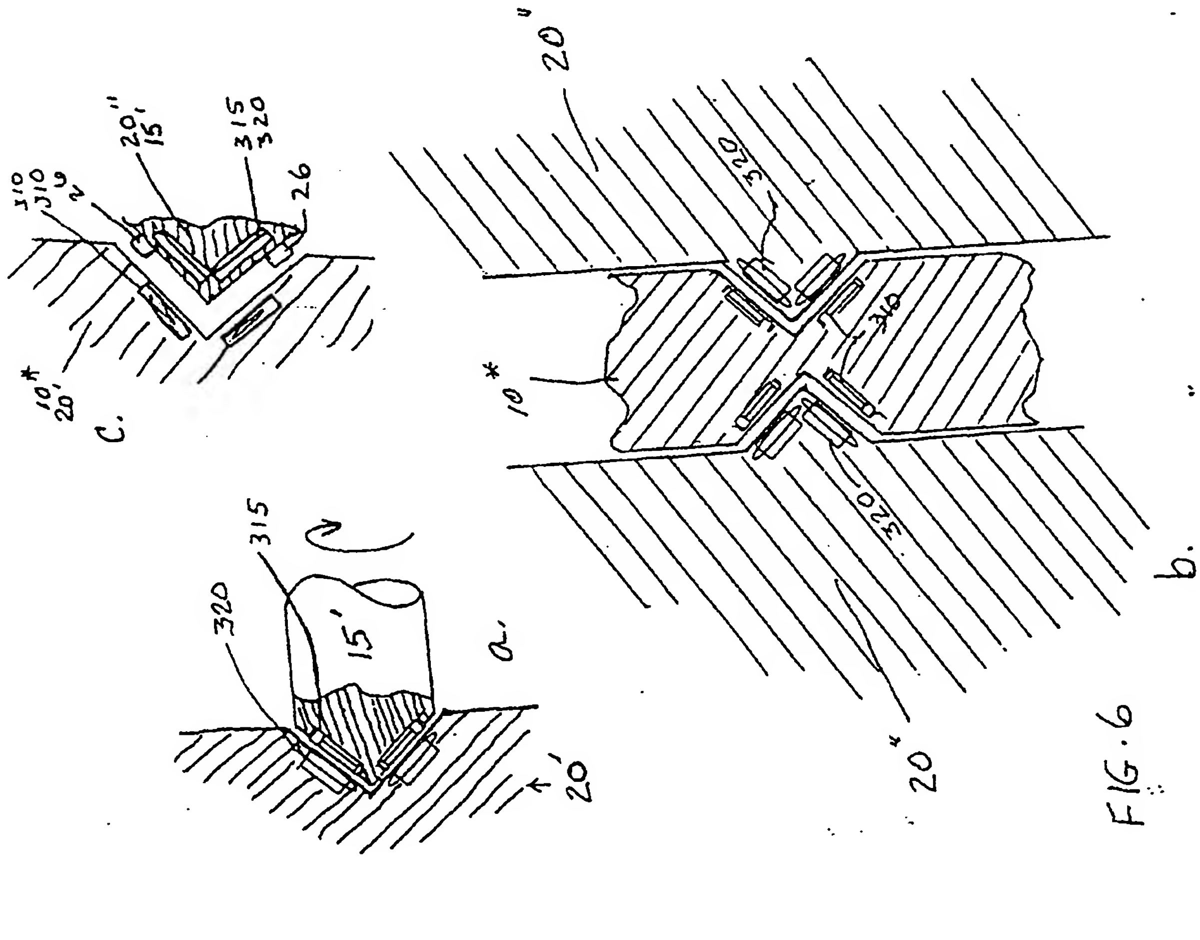
a.
320
315
15'
20'
c.
10*
20'
310
20''
15'
315
320
26
b.
20''
320
310
10*
320
20''

FIG. 6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 30 5428

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 5 545 017 A (STROHL WILLI ET AL) 13 August 1996 (1996-08-13) * column 2, line 65 - column 4, line 11; figures 1-3 *	1,6,10, 11	F04D5/00 F04D13/06
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A	EP 0 240 674 A (EBARA RES CO LTD) 14 October 1987 (1987-10-14) * abstract * * column 5, line 27 - column 6, line 1 * * column 11, line 15 - line 33; figures 3,9 *	1,11	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)
F04D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24 August 2000	Zidi, K

CATEGORY OF CITED DOCUMENTS

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